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Contract No:	N00014-85-K-0661
Period:	September 1, 1985 - September 30, 1990
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Name of Institution:	San Diego State University
Title of Project:	Schemas in Problem Solving: An Integrated Model of Memory, Learning, and Instruction
Principal Investigator:	Sandra P. Marshall

This document serves as the final technical report of ONR Contract No. N00014-85-K-0661. The project continues under ONR Grant No. N00014-90-J-1143.

Project Description. The purpose of the project was to develop a schema-based model of teaching and learning and to test the adequacy of that model in a computer-based instructional system. The domain of instruction is arithmetic word problems, and the schemas center on the situations that can be expressed in such problems.

A core set of situations was identified, and a series of studies verified that the situations were sufficient for describing virtually all legitimate word problems. A model of schema knowledge was constructed for each of the basic situations. Each schema model specified the feature knowledge, constraint knowledge, planning knowledge, and implementation knowledge required to use the schema successfully.

The instructional system, called *STORY PROBLEM SOLVER (SPS)*, was designed to provide instruction about these situations in such a way as to foster the development of appropriate schemas by individuals. The system consists of (a) a series of lessons requiring about 6-8 hours for completion and (b) a flexible problem-solving environment. Both of these components were designed to focus on specific aspects of schema knowledge required in solving problems.

In the lessons, each component of schema knowledge was addressed implicitly through short instructional segments and related exercises. Students were introduced to a set of icons depicting the situations, and they were encouraged to use the icons to represent the various situations occurring in specific problems. A set of experiments revealed that students did develop the specific types of schema knowledge targeted by SPS and that the icons were a key part of their knowledge. Moreover, we were able to chart the development of schemas over the course of instruction through individual interviews with our subjects.
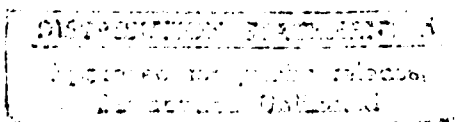
The second part of the system is a flexible problem-solving environment in which students can experiment with problem representations by manipulating the icons described above. Students are able to select a subset of icons to represent a problem and to link these together to represent the connections in the problem. They have options to expand the icons and explore individual aspects of each one, to carry out calculations, to select other icons if they so desire, or to have the system display a possible representation of the problem. This environment was developed under the original ONR Contract and evaluated under the project continuation as Grant N00014-90-J-1143.

Project Results. There are four major results. First, I have created a working computer-based system of instruction that can be used to teach students about solving word problems. The system has been used successfully with about 100 subjects to date (primarily college students with weak problem solving skills).

Second, I have developed and refined a theory of schema structure and acquisition. The theory builds on the general nature of schema knowledge found in the cognitive science and cognitive psychological literature but goes considerably beyond it. In particular, the theory allows operational definition of key components of a schema and thus allows empirical tests of whether individuals have acquired these pieces.

Third, as a direct result of studying the acquisition of schema knowledge and attempting to evaluate students' learning, I have formulated a new model of assessment. The model is a network model, and it stipulates the need for assessing both the number of nodes and the connectivity within the net. Thus, the project results allow us to use the theory of memory organization (i.e., schema theory) to model learning, instruction, and assessment. This result has had the most wide reaching impact. As can be seen from the attached list of publications and presentations, I have been invited to make a number of contributions about assessing schema knowledge. The importance here is that the theory developed during this project is unique in its use of a common model for learning, instruction, and assessment. Moreover, the theory provides the basis for a linkage between a psychological theory of memory/learning and a new psychometric theory of testing.

Fourth, the project has yielded several important modeling results. We have simulated successfully the performance of students as they respond to the computer exercises. The simulation uses estimates of their schema knowledge as revealed in interviews. Both correct and incorrect responses are equally well estimated. We have also employed a series of connectionist models which learn to classify the situations expressed in story problems. The modeling continues under the current project renewal.

Attached is a list of publications, technical reports, conference presentations, and invited addresses that report research from this project. Also listed are several in-progress activities, including a book that describes the project. per AD-A205594

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Publications:

Marshall, Sandra P. (1988). Assessing problem solving: A short-term remedy and a long-term solution. In R. I. Charles & E. A. Silver (Eds.), *The Teaching and Assessing of Mathematical Problem Solving.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Marshall, Sandra P. (1989). Affect in schema knowledge: Source and impact. In D. B. McLeod & V. M. Adams (Eds.), *Affect and mathematical problem solving.* New York: Springer Verlag.

Marshall, Sandra P. (1990). The assessment of schema knowledge for arithmetic story problems: A cognitive science perspective. In G. Kulm (Ed.), *Assessing higher order thinking in mathematics.* Washington, D.C.: AAAS.

Marshall, Sandra P. (1990). Generating good items for diagnostic tests. In N. Frederiksen, R. Glaser, A. Lesgold, & M. Shafto (Eds.), *Diagnostic Monitoring of Skill and Knowledge Acquisition.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Marshall, Sandra P. (in press). Assessing schema knowledge. In N. Frederiksen, R. Mislevy, & I. Bejar (Eds.), *Test Theory for a New Generation of Tests.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Marshall, Sandra P. (in press). Assessment of rational number understanding: A schema-based approach. In T. Carpenter, E. Fennema, & T. Romberg, *Rational Numbers: An Integration of Research.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Technical Reports:

Marshall, Sandra P., Pribe, Christopher A., & Smith, Julie D. (1987). *Schema Knowledge Structures for Representing and Understanding Arithmetic Story Problems.*

Marshall, Sandra P. (1988). *Assessing Schema Knowledge.*

Marshall, Sandra P. (1988). *Schema Knowledge for Solving Arithmetic Story Problems: Some Affective Components.*

Marshall, Sandra P., Barthuli, Kathryn E., Brewer, Margaret A., & Rose, Frederic E. (1989). *STORY PROBLEM SOLVER: A schema-based system of instruction.*

Marshall, Sandra P. (in press). *What Students Learn (and Remember) from Word-Problem Instruction.*

Marshall, Sandra P. (in press). *Computer-Based Assessment of Schema Knowledge in a Flexible Problem-Solving Environment.*

Presentations:

Marshall, Sandra P. (1987, April). Knowledge representation and errors of problem solving: Identifying misconceptions. In W. Montague (Chair), *Diagnosing Errors in Science and Mathematics.* Symposium conducted at the Annual Meeting of the American Educational Research Association, Washington, D.C.

Marshall, Sandra P. (1988, April). Assessing schema knowledge. In N. Frederiksen (Chair), *Test Theory for Tests Based on Cognitive Theory.* Symposium conducted at the Annual Meeting of the American Educational Research Association, New Orleans.

Marshall, Sandra P. (1989, January). The assessment of schema knowledge for arithmetic story problems. In G. Kulm (Chair), *Perspectives and Emerging Approaches for Assessing Higher Order Thinking in Mathematics.* Symposium conducted at the Annual Meeting of the American Association for the Advancement of Science (AAAS), San Francisco.

Marshall, Sandra P. (1990, April). What students learn (and remember) from word problem instruction. In S. Chipman (Chair), *Penetrating to the Mathematical Structure of Word Problems.* Symposium conducted at the Annual Meeting of the American Educational Research Association, Boston.

Invited Addresses:

"Remedial Instruction for Arithmetic Story Problems: A Cognitive Science Approach." Invited address to the National Council of Teachers of Mathematics, Chicago, April 1988.

"Schema Knowledge". Invited presentation to the Resource Center for Science and Engineering, University of Puerto Rico, November 1989.

Articles in Preparation:

Marshall, Sandra P. *Understanding the situations of arithmetic word problems: A basis for schema knowledge.*

Marshall, Sandra P. & Brewer, Margaret A. *Learning from icons: What you see is what you get, or is it?*

Book in Preparation:

Working title: *Schemas in Problem Solving: An Integrated Model of Instruction, Learning, and Assessment.* Negotiations under way with Cambridge University Press. Contract expected by September 1991.